

CROSS-REFERENCE TO RELATED APPLICATION

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Serial No. 08/023,918 filed February 26, 1993, by Kenneth Schofield and Mark Larson,
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BACKGROUND OF THE INVENTION

This invention relates generally to vision systems for vehicles and, more particularly, to rearview vision systems which provide the vehicle operator with scenic information in the direction rearward of the vehicle. More particularly, the invention relates to a rearview vision system utilizing image capture devices, such as CMOS imaging arrays and the like.

A long-felt need in the art of vehicle rearview vision systems has been to eliminate exterior rearview mirrors by utilizing image capture devices, such as cameras, in combination with dashboard displays. This would be beneficial because it would reduce wind drag on the vehicle, wind noise and vehicle weight. Furthermore, rearview mirrors protrude a substantial distance from the side of the vehicle, which makes maneuvering in tight spaces more difficult. Image capture devices are capable of positioning in a greater variety of locations on the vehicle, providing more flexibility of vehicle styling. It is further expected that camera systems would greatly reduce the blind spots to the sides and rear of the vehicle common with vehicles equipped with conventional rearview mirror systems. The driver cannot perceive vehicles, objects, or other road users in such blind spots without turning his or her body, which interferes with forward-looking visual activities.

1 Camera-based rearview vision systems for vehicles have not obtained
commercial acceptance. One difficulty with proposed systems has been that they present a
large amount of visual information in a manner which is difficult to comprehend. This
difficulty arises from many factors. In order to significantly reduce blind spots, multiple
5 image capture devices are typically positioned at various locations on the vehicle. The image
of an object behind the equipped vehicle is usually captured by more than one image capture
device at a time and displayed in multiple images. This may confuse the driver as to
whether more than one object is present. When multiple image capture devices are
positioned at different longitudinal locations on the vehicle, objects behind the vehicle are at
10 different distances from the image capture devices. This results in different image sizes for
the same object. This effect is especially noticeable for laterally extending images, such as a
bridge, highway crosswalk markings, the earth's horizon, and the like. Such images are at
different vertical angles with respect to the image capture devices. This results in different
vertical positions on the display causing the elongated image to appear disjointed.

15 A camera system provides a monocular view of the scene, compared to the
binocular, or stereoscopic, view obtained when the scene is viewed through a rearview
mirror. This makes the ability to judge distances in a camera system a problem. This effect
is most noticeable at distances close to the vehicle where stereoscopic imaging is relied upon
extensively by the driver in judging relative locations of objects. Therefore, known camera
20 systems fail to provide to the driver important information where that information is most
needed — at small separation distances from surrounding objects.

1 Another difficulty with camera systems is that, in order to provide a sufficient
amount of information, the camera system typically presents the driver with a greatly
increased field of view. This improves performance by further reducing blind spots at the
side and rear of the vehicle. However, an increased field of view is often obtained by
5 utilizing a wide-angle lens which introduces distortion of the scene and further impairs the
ability of the driver to judge distances of objects displayed. The problem with such
distortion of the scene is that the driver must concentrate more on the display and take a
longer time to interpret and extract the necessary information. This further distracts the
driver from the primary visual task of maintaining awareness of vehicles and other objects in
10 the vicinity of the driven vehicle.

SUMMARY OF THE INVENTION

15 The present invention is directed towards enhancing the interpretation of visual
information in a rearview vision system by presenting information in a manner which does
not require significant concentration of the driver or present distractions to the driver. This
is accomplished according to the invention in a rearview vision system having at least two
image capture devices positioned on the vehicle and directed rearwardly with respect to the
direction of travel of the vehicle. A display is provided for images captured by the image
capture devices. The display combines the captured images into an image that would be
achieved by a single rearward-looking camera having a view unobstructed by the vehicle. In
20 order to obtain all of the necessary information of activity, not only behind but also along
side of the vehicle, the virtual camera should be positioned forward of the driver. The image
synthesized from the multiple image capture devices may have a dead space which

1 corresponds with the area occupied by the vehicle. This dead space is useable by the driver's sense of perspective in judging the location of vehicles behind and along side of the equipped vehicle.

5 The present invention provides techniques for synthesizing images captured by individual, spatially separated, image capture devices into such ideal image, displayed on the display device. This may be accomplished according to an aspect of the invention by providing at least three image capture devices. At least two of the image capture devices are side image capture devices mounted on opposite sides of the vehicle. At least one of the image capture devices is a center image capture device mounted laterally between the side
10 image capture devices. A display system displays an image synthesized from outputs of the image capture devices. The displayed image includes an image portion from each of the image capture devices. The image portion from the center image capture device is vertically compressed.

15 It has been discovered that such vertical compression substantially eliminates distortion resulting from the spatial separation between the cameras and can be readily accomplished. In an illustrated embodiment, the image compression is carried out by removing selective ones of the scan lines making up the image portion. A greater number of lines are removed further away from the vertical center of the image.

20 The compression of the central image portion produces a dead space in the displayed image which may be made to correspond with the area that would be occupied by the vehicle in the view from the single virtual camera. Preferably, perspective lines are included at lateral edges of the dead space which are aligned with the direction of travel of

1 the vehicle and, therefore, appear in parallel with lane markings. This provides visual clues
to the driver's sense of perspective in order to assist in judging distances of objects around
the vehicle.

5 According to another aspect of the invention, image enhancement means are
provided for enhancing the displayed image. Such means may be in the form of graphic
overlays superimposed on the displayed image. Such graphic overlap may include indicia of
the anticipated path of travel of the vehicle which is useful in assisting the driver in guiding
the vehicle in reverse directions. Such graphic overlay may include a distance grid
indicating distances behind the vehicle of objects juxtaposed with the grid.

10 These and other objects, advantages, and features of this invention will become
apparent by review of the following specification in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Fig. 1 is a top plan view of a vehicle having a rearview vision system
according to the invention;

Fig. 2 is a side elevation of the vehicle in Fig. 1;

Fig. 3 is a front elevation of a display according to the invention;

Fig. 4 is the same view as Fig. 1 illustrating an alternative embodiment of the
invention;

Fig. 5 is a block diagram of an electronic system according to the invention;

20 Fig. 6 is the same view as Fig. 3 illustrating an alternate mode of operation of
the system;

1 ~~Fig. 7 is the~~ same view as Fig. 2 illustrating an alternative embodiment of the invention;

~~Fig. 8 is the~~ same view as Fig. 3 illustrating an alternative embodiment of the invention;

5 ~~Fig. 9 is the~~ same view as Figs. 1 and 4 illustrating an alternative embodiment of the invention;

~~Fig. 10 is the~~ same view as Figs. 3 and 8 illustrating an alternative embodiment of the invention; and

~~Fig. 11 is a~~ chart illustrating the horizontal row of pixels (n1, n2) on which an
10 object will be imaged from two longitudinally separated image capture devices as that object is spaced at different longitudinal distances from the image capture devices.

DESCRIPTION OF THE PREFERRED EMBODIMENT

 Referring now specifically to the drawings, and the illustrative embodiments depicted therein, a vehicle 10, which may be an automobile, a light truck, a sport utility
15 vehicle, a van, a bus, a large truck, or the like includes a rearview vision system, generally illustrated at 12, for providing a driver of the vehicle with a view rearwardly of the vehicle with respect to the direction of travel D of the vehicle (Fig. 1). Vision system 12 includes at least two side image capture devices 14 positioned, respectively, on opposite sides of vehicle 10 and a center image capture device 16 positioned on the lateral centerline of the vehicle.
20 All of the image capture devices are directed generally rearwardly of the vehicle. Rearview vision system 12 additionally includes an image processor 18 for receiving data signals from

1 image capture devices 14, 16 and synthesizing, from the data signals, a composite image 42
which is displayed on a display 20.

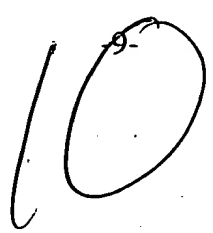
As will be set forth in more detail below, the images captured by image
capture devices 14, 16 are juxtaposed on display 20 by image processor 18 in a manner
5 which approximates the view from a single virtual image capture device positioned forwardly
of the vehicle at a location C and facing rearwardly of the vehicle, with the vehicle being
transparent to the view of the virtual image capture device. Vision system 12 provides a
substantially seamless panoramic view rearwardly of the vehicle without duplicate or
redundant images of objects. Furthermore, elongated, laterally-extending, objects, such as
10 the earth's horizon, appear uniform and straight across the entire displayed image. The
displayed image provides a sense of perspective, which enhances the ability of the driver to
judge location and speed of adjacent trailing vehicles.

Each of side image capture devices 14 has a field of view 22 and is aimed
rearwardly with respect to the vehicle about an axis 24 which is at an angle, with respect to
15 the vehicle, that is half of the horizontal field of view of the image capture device. In this
manner, each of the image capture devices 14 covers an area bounded by the side of the
vehicle and extending outwardly at an angle defined by the horizontal field of view of the
respective side image capture device. Center image capture device 16 has a horizontal field
of view 26, which is symmetrical about the longitudinal axis of the vehicle. The field of
20 view of each side image capture device 14 intersect the field of view of center image capture
device 16 at a point P which is located a distance Q behind vehicle 10.

1 Rear blind zones 30 are located symmetrically behind vehicle 10 extending
from the rear of the vehicle to point P. Side blind zones 25 located laterally on respective
sides of the vehicle extend rearwardly of the forward field of view 36 of the driver to the
field of view 22 of the respective side image capture device 14. An object will not be
5 captured by side image capture devices 14 or center image capture devices 16 if the object is
entirely within one of the blind zones 25, 30. In order for an object, such as another vehicle
V or other road user travelling to the side of vehicle 10, to be observed by an operator of
vehicle 10, the object must be either at least partially within the forward field of view 36 of
the driver or be captured by image capture devices 14, 16 and displayed on display 20. Fig.
10 4 illustrates vehicle 10 travelling on a three-lane highway having lanes L1, L2, and L3 with
the vehicle in lane L2. Another vehicle V is shown positioned mostly within one of the blind
zones 25, but with the rearmost portion of the vehicle V extending into field of view 22
where the vehicle image will be captured by one of side image capture devices 14. In the
illustrated embodiment, vehicle V is a motorcycle travelling in the center of lanes L1 or L3
15 and represents a worst case for observing a vehicle travelling at least partially within one of
the blind zones 25. In order for a portion of vehicle V to be extending either forwardly or
rearwardly of the respective blind zone 25, where the vehicle V may be observed by either
the forward field of view 36 of the driver or by the rearview vision system 12, the field of
view 22 of side image capture devices 14 must be sufficiently wide to capture a portion of
20 vehicle V as illustrated in Fig. 4. Preferably, the horizontal field of view 22 of side image
capture devices 14 is no greater than that required to provide sufficient coverage which
would be in the range of between approximately 55 degrees and approximately 70 degrees.

1 In the illustrated embodiment, the horizontal field of view 22 is 61 degrees. In order for a
portion of vehicle V to be within a vertical field of view 40 of one of side image capture
devices 14, the field of view should extend to the pavement at a plane M which intersects
vehicle V (Fig. 2). Preferably, vertical field of view 40 is between approximately 60
5 degrees and approximately 75 degrees. In the illustrated embodiment, vertical field of view
40 is 66 degrees.

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10 A left overlap zone 32 and a right overlap zone 34 extend rearward from
respective points P where the horizontal fields of view of the side image capture devices
intersect the field of view of center image capture device 16. Overlap zones 32, 34 define
areas within which an object will be captured both by center image capture device 16 and
one of the side image capture devices 14. An object in an overlap zone 32, 34 will appear
on display 20 in multiple image portions in a redundant or duplicative fashion. In order to
avoid the presentation of redundant information to the driver, and thereby avoid confusion
and simplify the task of extracting information from the multiple images or combined images
15 on display 20, the object should avoid overlapping zones 32, 34. In practice, this may be
accomplished to a satisfactory extent by moving points P away from the vehicle and thereby
increasing distance Q. It is desirable to increase distance Q to a length that will exclude
vehicles travelling at a typical separation distance behind vehicle 10 from overlapping zones
32, 34. This separation distance is usually a function of the speed at which the vehicles on
20 the highway are travelling. The faster the vehicles are travelling, the further Q should be
moved behind vehicle 10 to keep overlap zones 32 and 34 outside of the recommended
vehicle spacing. If, however, the vehicles are travelling at a slower speed, then the generally



1 accepted recommendation for vehicle spacing decreases and it is more likely that a vehicle
will be within overlap zone 32, 34. Therefore, the distance Q may be selected to
accommodate expected vehicle spacing for an average driving speed of vehicle 10.

Distance Q is a function of the effective horizontal field of view 26 of center
5 image capture device 16. As field of view 26 decreases, points P move further rearward of
the vehicle from a distance Q_1 , to a distance Q_2 , as best illustrated in Fig. 4. In order to
increase distance Q to eliminate redundant and duplicative information displayed on display
20 for most driving conditions of vehicle 10, field of view 26 is preferably less than 12
degrees. In the illustrated embodiment, field of view 26 is between 6 and 8 degrees.

10 Alternatively, distance Q may be dynamically adjusted according to some parameter, such as
the speed of vehicle 10. This would allow Q to be greater when the vehicle is travelling at a
faster speed, where vehicle separation tends to be larger, and vice versa. Field of view 26
may be adjusted by utilizing a selective presentation of pixels of the captured image in the
displayed image.

15 Referring to Fig. 3, image display device 20 displays a composite image 42
made up of a left image portion 44, a right image portion 46, and a center image portion 48.
Each image portion 44-48 is reversed from the image as captured by the respective image
capture device 14, 16 utilizing conventional techniques. These techniques include reading
the image in reverse with the image capture device, writing the image in reverse to display
20 device 20, or reversing the image in image processor 18. Left image portion 44 is joined
with central image portion 48 at a boundary 50. Central image portion 48 is joined with
right image portion 46 at a boundary 52. As may best be seen in Fig. 3, the image portions

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1 at boundaries 50 and 52 are continuous whereby composite image 42 is a seamless panoramic
view rearwardly of the vehicle. As also is apparent from Fig. 3, central image portion 48 is
narrower than either left image portion 44 or right image portion 46. This is a result of
reducing the horizontal field of view 26 of center image capture device 16 sufficiently to
5 move points P, and thus overlap zones 32 and 34, a sufficient distance behind vehicle 10 to
reduce redundant and duplicative images between image portions 44-48. Composite image
42 provides a clear image, which avoids confusion and simplifies the task of extracting
information from the multiple image portions 44-48. As also may be seen by reference to
Fig. 3, display 20 may additionally include indicia such as the readout of a compass 54,
10 vehicle speed 56, turn signals 58, and the like as well as other graphical or video displays,
such as a navigation display, a map display, and a forward-facing vision system. In this
manner, rearview vision system 12 may be a compass vision system or an information vision
system.

15 In the embodiment of rearview vision system 12 having a dynamically adjusted
value of distance Q, the spacing between boundaries 50 and 52 will dynamically adjust in
sequence with the adjustment of distance Q. Thus, as overlap zones 32, 34 move further
away from the vehicle; for example, in response to an increase in speed of the vehicle,
boundary lines 50 and 52 will move closer together and vice versa. In this manner,
composite image 42 is dynamic, having image portions of dynamically adaptive sizes.

20 Display 20 is of a size to be as natural as possible to the driver. This is a
function of the size of the display and the distance between the display and the driver.
Preferably, the displayed image simulates an image reflected by a rearview mirror. As such,

1 the size of display 20 is approximately the combined areas of the three rearview mirrors (one
interior mirror and two exterior mirrors) conventionally used with vehicles. As best seen by
reference to Fig. 2, display 20 is preferably positioned within the driver's physiological field
of view without obstructing the view through the windshield. It is known that the driver's
5 field of view, with the head and eyes fixed forward, extends further in a downward direction
than in an upward direction. Display 20 could be located above the vertical view through the
windshield wherein the display may be observed at the upward portion of the driver's field of
view. However, the position for the display illustrated in Fig. 2 is preferred wherein the
display is within the lower portion of the driver's field of view.

10 Display 20, in the illustrated embodiment, is a flat panel display, such as a
back-lit liquid crystal display, a plasma display, a field emission display, or a cathode ray
tube. However, the synthesized image could be displayed using other display techniques
such as to provide a projected or virtual image. One such virtual display is a heads-up
display. The display may be mounted/attached to the dashboard, fascia or header, or to the
15 windshield at a position conventionally occupied by an interior rearview mirror.

Although various camera devices may be utilized for image capture devices
14, 16, an electro-optic, pixelated imaging array, located in the focal plane of an optical
system, is preferred. Such imaging array allows the number of pixels to be selected to meet
the requirements of rearview vision system 12. The pixel requirements are related to the
20 imaging aspect ratio of the respective image capture devices, which, in turn, are a function
of the ratio of the vertical-to-horizontal field of view of the devices, as is well known in the
art. In the illustrated embodiment, the imaging aspect ratio of side image capture devices 14

1 is 2:1 and the image aspect ratio of central image capture device 16 is variable down to
0.1:1. Such aspect ratio will produce images which will not typically match that of
commercially available displays. A commercially available display may be used, however,
by leaving a horizontal band of the display for displaying alpha-numeric data, such as
5 portions of an instrument cluster, compass display, or the like, as illustrated in Fig. 3.

In the illustrated embodiment, image capture devices 14, 16 are CMOS
imaging arrays of the type manufactured by VLSI Vision Ltd. of Edinburgh, Scotland, which
are described in more detail in co-pending United States patent application Serial No.
No. 5,550,677 issued to
08/023,918 filed February 26, 1993, by Kenneth Schofield and Mark Larson for an
10 AUTOMATIC REARVIEW MIRROR SYSTEM USING A PHOTSENSOR ARRAY, the
disclosure of which is hereby incorporated herein by reference. However, other pixelated
focal plane image-array devices, which are sensitive to visible or invisible electromagnetic
radiation, could be used. The devices could be sensitive to either color or monochromatic
visible radiation or near or far infrared radiation of the type used in night-vision systems.
15 Each image capture device could be a combination of different types of devices, such as one
sensitive to visible radiation combined with one sensitive to infrared radiation. Examples of
other devices known in the art include charge couple devices and the like.

Preferably, image capture devices 14 and 16 are all mounted at the same
vertical height on vehicle 10, although compromise may be required in order to
20 accommodate styling features of the vehicle. The horizontal aim of image capture devices 14
and 16 is preferably horizontal. However, the portion of the image displayed is preferably

1 biased toward the downward portion of the captured image because significantly less useful
information is obtained above the horizontal position of the image capture devices.

Each image-capturing device 14, 16 is controlled by appropriate supporting
electronics (not shown) located in the vicinity of the imaging array such that, when operating
5 power is supplied, either an analog or a digital data stream is generated on an output signal
line supplied to image processor 18. The support electronics may be provided partially on
the image chip and partially on associated electronic devices. For each exposure period, a
value indicative of the quantity of light incident on each pixel of the imaging array during the
exposure period is sequentially outputted in a predetermined sequence, typically row-by-row.

10 The sequence may conform to video signal standards which support a direct view such that,
when a scene is viewed by an image-capturing device, the image presented on a display
represents directly the scene viewed by the image-capturing devices. However, when
looking forward and observing a displayed image of a rearward scene, the driver will
interpret the image as if it were a reflection of the scene as viewed through a mirror.

15 Objects to the left and rearward of the vehicle, as viewed by the rearward-looking camera,
are presented on the left-hand side of the display and vice versa. If this reversal is effected
in image processor 18, it may be by the use of a data storage device, or buffer, capable of
storing all of the pixel values from one exposure period. The data is read out of the data
storage device in a reversed row sequence. Alternatively, the imaging array electronics
20 could be constructed to provide the above-described reversal at the image-capturing device or
at the display.

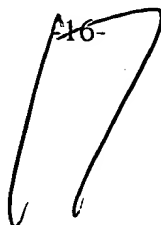
1 Data transmission between image capture devices 14, 16 and image processor
18 and/or between image processor 18 and display 20 may be by electrically conductive leads
or fiber-optic cable. It is possible, for particular applications, to eliminate image processor
18 and direct drive display 20 from image capture devices 14, 16 at the pixel level.

5 The data streams from image-capturing devices 14, 16 are combined in image
processor 18 and directly mapped to the pixel array of display 20. This process is repeated
preferably at a rate of at least 30 times per second in order to present an essentially real time
video image. The image captured by side image capture device 14 on the right side of the
vehicle is presented in right image portion 46 and the image from side image capture device
10 14 on the left side of the vehicle is displayed on left image portion 44. The image from
center image capture device 16 is displayed on central image portion 48. The three image
portions 44-48 are presented in horizontal alignment and adjacent to each other. However,
the composite image may be positioned at any desired vertical position in the display 20. It
is also possible to display image portions 44-48 on separate image devices which are adjacent
15 each other.

In vision system 12, side image capture devices 14 are positioned preferably at
a forward longitudinal position on vehicle 10 and center image capture device 16 is
positioned at a rearward longitudinal position on the vehicle. As best seen by reference to
Fig. 7, this positioning creates a difference in the vertical angle between each side image
20 capture device 14 and center image capture device 16 with respect to a fixed location P_1 that
is a distance D_1 behind the vehicle. This difference in sensing angle will cause each side
image capture device 14 to image an object located at P_1 on a horizontal row of pixels that is

1 different from the horizontal row of pixels that center image capture device 16 will image the
same object. If the image is below the horizontal centerline of the image capture device, it
will be imaged on a lower row of pixels by center image capture device 16 than the row of
pixels it will be imaged by the side image capture devices 14, as illustrated in Fig. 7. This
5 mismatch between horizontal pixel rows of the captured image is furthermore a function of
the distance of the captured image from the rear of the vehicle. This can be understood by
reference to Fig. 11 which presents a chart 90 having a first column 92 of pixel lines n1,
measured from the array centerline, at which an object will be imaged by side image capture
device 14 and a second column 94 of pixel lines n2, measured from the array vertical
10 centerline, at which the same object will be imaged by center image capture device 16. The
result is that an object, which is captured by both side and center image capture devices 14,
16, will be vertically disjointed at the boundary of the displayed image, if the object is
captured by more than one image capture device. The amount of disjointment will be greater
closer to the vehicle and less at further distances. If the object is elongated in the horizontal
15 direction, such as earth's horizon, bridges, or cross-markings on highways, then the object
will appear to be either broken or crooked.

In order to provide uniform display of laterally elongated images, a rearview
vision system 12' is provided having a central image portion 48' which is processed
differently from the image display portions 44' and 46' produced by the side image capture
20 devices (Fig. 8). Central image portion 48' is reduced vertically, or compressed, by
removing specified scan lines, or pixel rows, from the image captured by center image
capture device 16 in a graduated fashion. The difference in the pixel line at which an object



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1 will be imaged by each of the side and center image capture devices is a function of the distance D of the object from the rear of the vehicle, with a greater variation occurring at shorter distances and the variation reducing to zero for infinite distances. Therefore, the compression of central image portion 48' is non-linear, with substantially no compression at the vertical center of the image and greater compression at greater distances above and below the vertical center point of the image. This is accomplished by removing specific lines from the center display in a graduated fashion with a greater number of lines removed further from the vertical center of the image. The removed lines may be merely discarded in order to vertically reduce the image. Alternatively, the data contained in the removed lines may be utilized to modify the value of adjacent pixels above and below the removed line in order to enhance the quality of the compressed image. Averaging, median filtering, or other such known techniques may also be used.

Each of right image portion 46' and left image portion 44' includes an upper portion 64 which extends above the compressed upper portion of the central image portion 48'. In the illustrated embodiment, upper portions 64 are deleted in order to present a uniform upper horizontal boundary for display 20'. In the illustrated embodiment, the mismatch between the lower horizontal boundary of central image portion 48' and each of the left and right image portions provides a dead space 66 which provides a visual prompt to the user of the approximate location of the rearward corners S of vehicle 10. This dead space 66 in the image displayed on display 20' approximates the footprint occupied by vehicle 10 when viewed from point C. This is particularly useful because it provides a visual indication to the driver that a vehicle passing vehicle 10, as viewed in either left image

1 portion 44' or right image portion 46', is at least partially adjacent vehicle 10 if the image of the approaching vehicle is partially adjacent to dead space 66.

In an alternative embodiment, the vertical compression technique may be applied to only a lower vertical portion of central image portion 48'. In most driving situations, objects imaged by rearward-facing image capture devices above the horizon are at a long distance from the vehicle while those below the horizon get progressively closer to the vehicle in relation to the distance below the horizon in the displayed image. Therefore, compression of the upper vertical portion of the central image portion may be eliminated without significant reduction in performance.

Compression of the central image portion may also advantageously be provided horizontally, as well as vertically. Spatial separation of center image capture device 16 from side image capture devices 14 causes similar distortion, as that described above, in the horizontal direction. This effect is spherical in nature and would require a more complex corrective action, such as compressing the image based upon the removal of pixels from an approximation to concentric circles centered on the center of the imaging array, or other techniques which would be apparent to those skilled in the art.

A rearview vision system 12'' includes an image display 20'' having a compressed central image portion 48'' and left and right image portions 44'' and 46'', respectively (Fig. 10). A border 50' between left side image 44'' and central image 48'' includes a vertical central border portion 50a', an upper border portion 50b', and a lower border portion 50c'. Upper border portion 50b' and lower border portion 50c' diverge laterally outwardly, vertically away from central portion 50a'. A border 52' between central

1 image portion 48'' and right image portion 46'' includes a central boundary portion 52a', an
upper boundary portion 52b', and a lower boundary portion 52c'. Upper boundary portion
52b' and lower boundary portion 52c' diverge laterally outwardly vertically away from
central portion 52a'. This creates an upper portion of central image portion 48'' and a lower
5 portion of central image portion 48'' which extend beyond the center portion thereof. This
configuration is based upon the realization that the surface of the road immediately behind
the vehicle is captured by central image capture device 16. Likewise, the horizontal plane
above the vehicle, which is symmetrical with the road surface, is captured by the center
image capture device. This may be seen by referring to point P in Fig. 10, which illustrate
10 the points where the effective radius 68 of the virtual image capture device intersects dead
zones 30 and by referring to point S in Fig. 10 which illustrates the corners or the rear of the
vehicle (S).

The image displayed on display 20'' includes a dead space 66' having
diverging lateral sides 68a, 68b. Diverging sides 68a and 68b are configured in order to
15 extend in the direction of travel of vehicle 10 which is parallel to lane markings of a highway
on which vehicle 10 is travelling. This further enhances the visual perception of the driver
by providing a visual clue of the location of images appearing on display 20'' with respect to
the vehicle 10. Side portions 68a, 68b, in the illustrated embodiment, are natural extensions
of lower boundary portions 50c' and 52c' and extend from point S on each respective side of
20 the vehicle to point R, which represents the intersection of the lower extent of the vertical
field of view 40 of each side image capture device 14 with the pavement (Fig. 7).

1 Rearview vision systems 12' and 12'' utilize a displayed synthesized image
which takes into account the use of perspective in enhancing the driver's understanding of
what is occurring in the area surrounding the vehicle. The images produced on displays 20'
and 20'' effectively remove the vehicle bodywork and replace the bodywork with a vehicle
5 footprint as would be viewed by virtual camera C. The image displayed on display 20''
further includes perspective lines which further enhance the roll of perspective in the driver's
understanding of what is occurring.

10 In order to further enhance the driver's understanding of what is occurring in
the area surrounding the vehicle, a rearview vision system 12''' includes a display 20'''
having image enhancements (Fig. 6). In the illustrative embodiment, such image
enhancements include graphic overlays 70a, 70b which are hash marks intended to illustrate
to the driver the anticipated path of movement of vehicle 10. In the illustrated embodiment,
the anticipated vehicle motion is a function of the vehicle direction of travel as well as the
rate of turn of the vehicle. The forward or rearward direction of vehicle travel is determined
15 in response to the operator placing the gear selection device (not shown) in the reverse gear
position. The degree of turn of the vehicle may be determined by monitoring the movement
of the vehicle steering system, monitoring the output of an electronic compass, or monitoring
the vehicle differential drive system. In the embodiment illustrated in Fig. 6, the
configuration of graphic overlays 70a, 70b indicates that the vehicle is in reverse gear and
20 that the wheels are turned in a manner that will cause the vehicle to travel toward the
driver's side of the vehicle. If the wheels were turned in the opposite direction, graphic
overlays 70a, 70b would curve clockwise toward the right as viewed in Fig. 6. If the

1 vehicle's wheels were straight, graphic overlays 70a, 70b would be substantially straight
converging lines. If the vehicle is not in reverse gear position, graphic overlays 70a, 70b are
not presented. Other types of graphic overlays of the displayed image are comprehended by
the invention.

5 Horizontal grid markings on the display may be provided to indicate distances
behind the vehicle at particular markings. Such grid would allow the driver to judge the
relative position of vehicles behind the equipped vehicle. In one embodiment, short
horizontal lines are superimposed on the displayed image at regular rearward intervals in
horizontal positions which correspond to the boundaries of the lane in which the vehicle is
10 travelling. In order to avoid confusion when the vehicle is travelling in a curved path, from
a lack of correspondence between the graphic overlay and the road, a signal indicative of the
vehicle's rate of turn may be taken into account when generating the graphic overlay. In this
manner, the distance indications may be moved laterally, with reduced horizontal separation,
to correspond to the positions of the curved lane boundaries and vertically on the image to
15 compensate for the difference between distances along a straight and curved path.

Another image enhancement is to alter the appearance of an object in a
particular zone surrounding the vehicle in order to provide an indication, such as a warning,
to the driver. As an example, a vehicle that is too close to the equipped vehicle for safe-lane
change, may be displayed in a particular color, such as red, may flash, or otherwise be
20 distinguishable from other images on the display. Preferably, the speed of the equipped
vehicle 10, which may be obtained from known speed transducers, may be provided as an
input to the rearview vision system in order to cause such warning to be a function of the

1 vehicle speed which, in turn, affects the safe separation distance of vehicles. The operation
of the turn signal may also be used to activate such highlighting of other road users or to
modify the scope of the image displayed. In order to determine the distance of objects
behind vehicle 10, a separate distance-measuring system may be used. Such separate system
5 may include radar, ultrasonic sensing, infrared detection, and other known distance-
measuring systems. Alternatively, stereoscopic distance-sensing capabilities of side image
capture devices 14 may be utilized to determine the separation distance from trailing objects
utilizing known techniques.

Thus, it is seen that the image displayed on display 20-20''' may be different
10 under different circumstances. Such different circumstances may relate to the vehicle's
direction of travel, speed, rate of turn, separation from adjacent objects, and the like.

Various other forms of image processing may be utilized with rearview vision
system 12-12'''. Luminant and chrominant blending may be applied to the images captured
by image capture devices 14, 16 in order to produce equality of the image data whereby the
15 image portions appear as if they were produced by one image capture device. The dynamic
range of the image capture devices may be extended in order to provide high quality images
under all lighting conditions. Furthermore, individual pixel groups may be controlled in
order to selectively compensate for bright or dark spots. For example, anti-blooming
techniques may be applied for bright spots. Multiple exposure techniques may be applied to
20 highlight dark areas. Image morphing and warping compensation techniques may
additionally be applied. Resolution of the image capture devices and display may be selected
in order to provide sufficient image quality for the particular application.

1 A heater may be applied to each image capture device in order to remove dew
and frost that may collect on the optics of the device. Although, in the illustrative
embodiment, the optical centerline of the camera coincides with the field of view, particular
applications may result in the centerline of the camera pointing in a direction other than the
5 centerline of the field of view. Although, in the illustrative embodiment, the image capture
devices are fixed, it may be desirable to provide selective adjustability to the image capture
devices or optical paths in particular applications. This is particularly desirable when the
system is used on articulated vehicles where automated and coordinated camera aim may be
utilized to maintain completeness of the synthesized image.

10 When operating the vehicle in the reverse direction, it may be desirable to
provide additional data concerning the area surrounding the immediate rear of the vehicle.
This may be accomplished by utilizing non-symmetrical optics for the center image capture
device in order to provide a wide angle view at a lower portion of the field of view.
Alternatively, a wide angle optical system could be utilized with the electronic system
15 selectively correcting distortion of the captured image. Such system would provide a
distortion-free image while obtaining more data, particularly in the area surrounding the back
of the vehicle.

20 The invention additionally comprehends the use of more than three image
capture devices. In addition to side image capture devices positioned at the front sides of the
vehicle and a center image capture device positioned at the center rear of the vehicle,
additional image capture devices may be useful at the rear corners of the vehicle in order to
further eliminate blind spots. It may additionally be desirable to provide an additional center

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1 image capture device at a higher elevation in order to obtain data immediately behind the
vehicle and thereby fill in the road surface detail immediately behind the vehicle. Such
additional detail is particularly useful when operating the vehicle in the reverse direction. Of
course, each of the image capture devices could be a combination of two or more image
5 capture devices.

Although the present invention is illustrated as used in a rearview vision
system, it may find utility in other applications. For example, the invention may be useful
for providing security surveillance in an area where a building or other object obstructs the
view of the area under surveillance. Additionally, the invention may find application in
10 night-vision systems and the like. For example, the invention may be applied to forward-
facing night-vision systems, or other vision enhancement systems such as may be used in
adverse weather or atmospheric conditions such as fog, applied to provide an enhanced
display of a synthesized image, which approximates a forward-facing view from a single
virtual camera located rearwardly of the driver, taking advantage of the perspective features
15 of the image.

Thus, it is seen that the present invention enhances the relationship between
the driver's primary view and the image presented on the rearview vision system. This is
accomplished in a manner which provides ease of interpretation while avoiding confusion so
that the driver does not have to concentrate or look closely at the image. In this manner,
20 information presented on the display is naturally assimilated. This is accomplished while
reducing blind spots so that other vehicles or objects of interest to the driver will likely be

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1 displayed to the driver. Additionally, the use of perspective allows distances to be more accurately determined.

Changes and modifications in the specifically described embodiments can be carried out without departing from the principles of the invention, which is intended to be
5 limited only by the scope of the appended claims, as interpreted according to the principles of patent law including the doctrine of equivalents.

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